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Use of a Spectroradiometer to Study Aerial Photographs of Ozone-Treated Soybeans

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16. ABSTRACT

A scanning spectroradiometer was used to measure the optical densities of an aerial photograph of an experimental field in which soybeans were growing in response to different concentrations of ozone, an air pollutant. The plants were growing in 3 m diameter, 2.4m high open-top exposure chambers. Correlation coefficients among the film densities, plant yield and visual estimates of non-green leaf area for the 16 test plots were highly significant ($p<0.0$); those with ozone treatment concentrations were significant ($p<0.05$). The early senescence induced by this form of environmental stress can thus be detected by film density differences., and these differences are well correlated with ground indicators of crop condition.

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The use of a spectroradiometer to study aerial photographs of ozone-treated soybeans

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Abstract. A scanning spectroradiometer was used to measure the optical densities of an aerial photograph of an experimental field in which soybeans were growing in response to different concentrations of ozone, an air pollutant. The plants were growing in 3 m diameter, 2·4 m high open-top exposure chambers. Correlation coefficients among the film densities, plant yield and visual estimates of non-green leaf area for the 16 test plots were highly significant ($p < 0{\cdot}01$); those with ozone treatment concentrations were significant ($p < 0{\cdot}05$). The early senescence induced by this form of environmental stress can thus be detected by film density differences, and these differences are well correlated with ground indicators of crop condition.

1. Introduction

Estimation of crop condition with remotely-sensed data requires an understanding of how the spectral properties of the plants relate to yield. These data can be best obtained with crops growing in response to experimentally-imposed stress regimes. Field experiments to evaluate the effects of air pollution on crops provide an ideal opportunity to gather these data. Experimental plants are typically grown in open-top chambers and exposed to different, carefully regulated levels of a gaseous pollutant throughout the growing season (Heagle *et al.* 1973, 1986). As the plants are all in the same field, differences due to variations in soil type and climate are minimal. Ozone (O_3), a photochemical oxidant, is frequently the pollutant studied as it is widespread and particularly phytotoxic (Heck *et al.* 1986).

It has already been shown that the effects of O_3 treatment on soybeans are detectable with spectral measurements (Cure *et al.* 1988). Ozone causes the plants to reach senescence prematurely which reduces yield by shortening the time during which they can photosynthesize and produce dry matter for seeds. Premature senescence was obvious spectrally as chlorosis. In this letter, we will show that the effects of O_3 treatment are also detectable in film density measurements obtained from aerial photographs of an experimental field site in which soybeans were growing at different O_3 levels in open-top chambers. The film density data will be compared with visual ratings of non-green leaf area by an observer on the ground as well as with yield and the O_3 treatment levels.

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2. Materials and methods

The experiment was conducted in a field 5 km south of Raleigh, North Carolina, U.S.A. Soybeans, *Glycene max* L Merr. 'Davis', were planted 29 June 1982 in a 0·8 ha field in north–south rows spaced 1 m apart. Treatment plots were selected on the basis of uniformity and thinned to 18 plants per metre of row. Open-top chambers, 3 m in diameter and 2·4 m high (Heagle *et al.* 1973), were placed over two rows of plants. Ozone exposures began on 20 July and continued for 7 hours each day from 09.00 to 16.00 EST, except on rainy days, until 17 October. Ozone treatment concentrations (μLL^{-1}) were expressed as the 7 hour per day mean over the exposure portion of the growing season. Plants were harvested on 8 November.

Eight O_3 treatments were randomly assigned to plots within each of two blocks. Six treatment plots within each block were maintained at O_3 concentrations greater than ambient by addition of O_3 during the 7-hour exposure period. In three of these, O_3 was added in proportion to that present in the ambient air (1·3, 1·6 or 1·9 times ambient; the 1·3, 1·6 and 1·9 treatment). In the other three plots, constant amounts of O_3 were added (0·02, 0·04, or 0·06 μLL^{-1} treatments). No O_3 was added to one plot, the non-filtered (NF) air treatment, and the other, all air entering through the chamber air distribution system was charcoal-filtered (the CF treatment). In the CF plots, O_3 concentrations ranged from one-third to one-half the ambient levels due to ingress of ambient air through the open chamber top. In total, 16 chambered plots were available for study.

Aerial photographs were obtained using the Environmental Protection Agency's (EPA) KA-85A camera loaded with Kodak Aerochrome Infrared film 2443 (with a Wratten 12 filter). The overflight took place at 12.30 EST on 24 September with the aircraft at an altitude of 250 m above ground level. The photograph used in the analysis was from the nadir-viewing camera. Density measurements were made from a positive transparency (Aerochrome duplicating film 2447) supplied by EPA. The image of the entire experimental area was in the centre of the frame (distortion was negligible as checked by measuring the diameters of the chamber frames). The centre of the film frame was cut out and sandwiched between two microscope slides for analysis.

A Jenoptic Jena GmbH Documator DL-2 microfilm reader was connected to Spectron Engineering's SE-590 field portable data-logging spectroradiometer with a Gamma Scientific 914 mm by 3·18 mm flexible fiberoptic cable (figure 1). The face of the cable was mounted flush to, and a little above centre of, the viewing area of the DL-2. The other end was mounted in front of the entrance slit of the detector of the SE-590. The detector was a 256 photodiode array. It acquired a contentious spectra from 368·4–1113·7 nm in 16 microseconds. The dispersion over the 256 element array, is 2·6 nm per photodiode. Data are stored on a micro-digital cassette tape. The output of the data logger is to a printer and/or an oscilloscope. Printer output can be the raw data, reference curve, sample curve or ratio curve of the sample and reference panel. The ratio curve was used in this study. As no reference panel was on the ground, the flat, corrugated metal roof of a building was used as a reference within the frame. As this was specular it could have added a large error to the method.

The 17·5× magnification, of the DL-2, gave an image size of 10 mm for each chamber. The fiberoptic cable's face covered 3 mm of each row (figure 2). Readings were made at the centre of each one of the rows in the chamber by centring the row on the face of the probe.

Film density ratio values (FDRV), were determined from the ratio curve by dividing the maximum ratio value of the first peak by the maximum ratio value of the second peak (Shih 1984), FDRV = I − 1/I − 2 (figure 3).

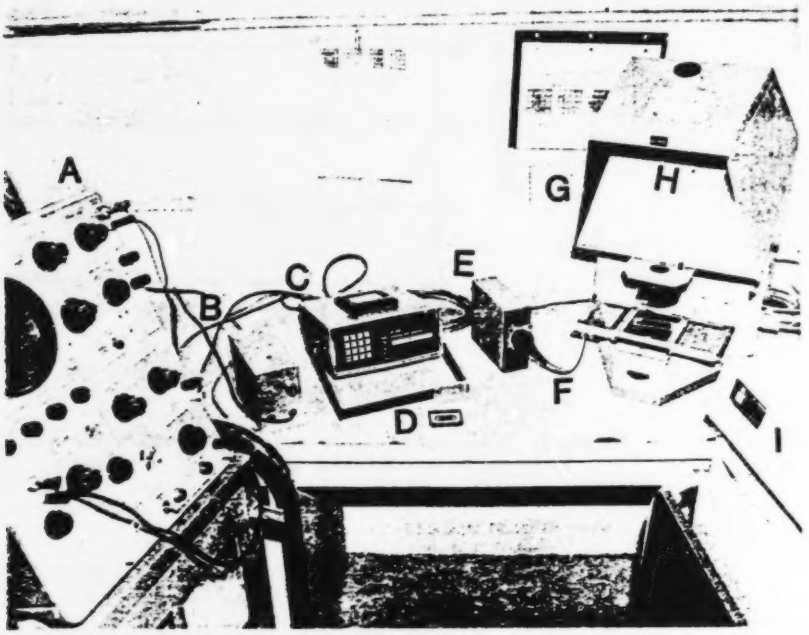

Figure 1. Spectroradiometric equipment. A, Oscilloscope; B, 110 VAC to 12 VDC transformer; C, data-logger; D, microdigital cassette; E, detector; F, fiberoptic cable; G, Microfilm reader; H, fiberoptic face; and I, printer.

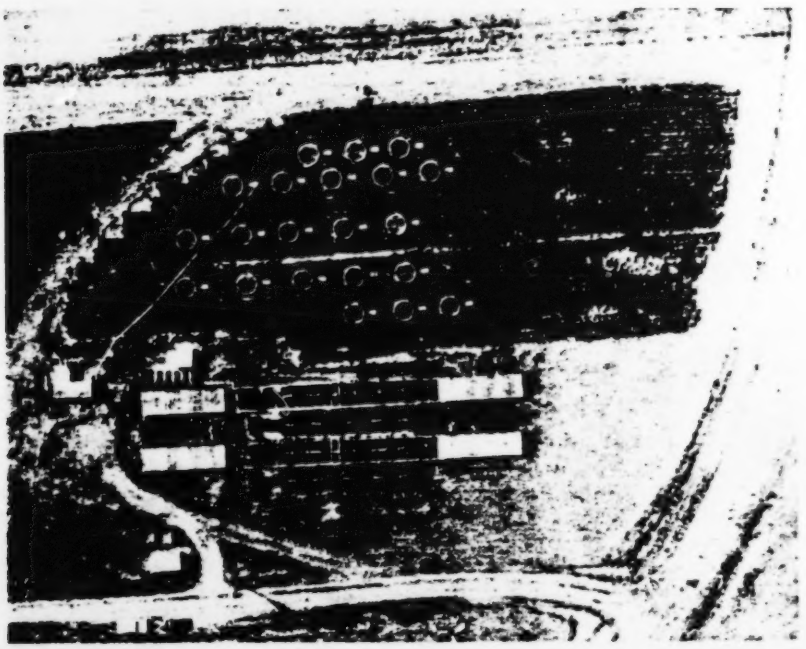

Figure 2. The central portion of an aerial photograph of the experimental field.

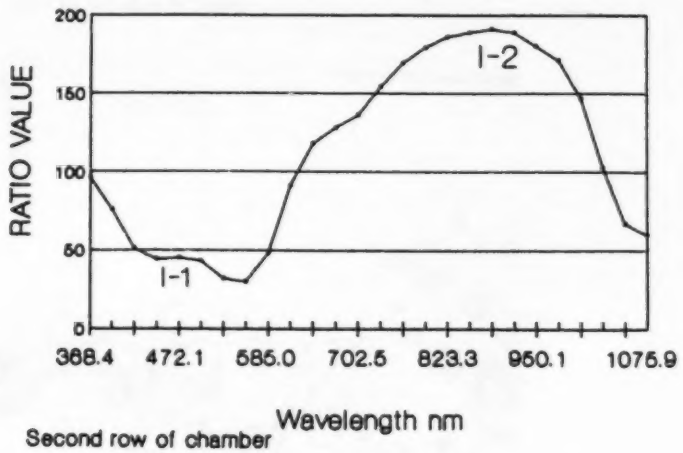

Figure 3. Ratio curve of one row of the chamber, 0·02 μLL^{-1} ozone concentration. I – 1 = maximum ratio value, first peak; I – 2 = maximum ratio value, second peak.

Visual estimates of non-green leaf area were made on 23 September, the day before the overflight. These were the plot average of non-green leaf area estimated in 5 per cent increments (0–100 per cent) for the top eight trifoliates arising from the main stem of four randomly chosen plants (one in each quadrant). All estimates were made by the same individual. Comparisons among visual ratings (following an arcsin-

Correlations among soybean treatment data and film density ratio values.

	Individual plot values ($n = 16$)		
	$[O_3]$	Visual estimates	Film density ratio value
Yield†	−0·89**	−0·89*	−0·67**
$[O_3]$‡	—	0·89**	0·60*
Visual estimates	—	—	0·67**

	Treatment means ($n = 8$)		
	$[O_3]$	Visual estimate	Film density ratio value
Yield†	−0·93**	−0·96**	−0·87**
$[O_3]$‡	—	0·95**	0·78*
Visual estimates	—	—	0·91**

† Soybean yield (seed dry weight), gm^{-1} row^{-1}.
‡ Ozone treatment concentration, μLL^{-1}.
* Significant with $p < 0·05$.
** Significant with $p < 0·01$.

square root transformation), film density ratio values and soybean yields were based upon correlation coefficients estimated using both individual plot values ($n=16$) and treatment means ($n=8$).

3. Results and discussion

Correlation coefficients among the film density measurements, soybeans, O_3 treatment concentrations and visual estimates of non-green leaf area (table) were significant, whether based upon the individual observations ($n=16$) or treatment means ($n=8$). (A typical ratio curve from one of the two rows within a chamber is depicted in figure 3. The ratio of I−1 to I−2 was the film density variable.) Use of treatment means, however, resulted in generally higher correlations, especially for relations with the film density measurements. Thus efforts to model soybean yield as a function of film density would be enhanced by the availability of data from as great a number as possible of similar experimental plots.

Though film density was well correlated with the O_3 treatment levels, as were ground-based spectral observations (Cure *et al.* 1988), it must be emphasized that all of these measurements are primarily detecting chlorosis. Ozone is but one form of environmental stress that speeds the natural process of senescence in these plants; water deficits, for example, also cause premature senescence in soybean and a subsequent reduction in yield (Constable and Hearn 1978). Thus it would be difficult to assign a specific cause to early, yield-reduction senescence detected spectrally in film or broad-band ground-based measurements. However, as our data show, early senescence is detectable and quantifiable with spectral observations. Information gained from additional field experiments will be required to develop models of crop condition utilizing spectral measurements, experiments that would have to take into account such factors as, in addition to species, varietal differences, climate effects, soil differences and planting date.

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The use of trade names does not imply endorsement nor criticism of similar products not mentioned.

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